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METALS (Cu, Ni, Fe, Co, Zn, Pb) AND RADIONUCLIDE (Ra-226) LEVELS IN MEADOW VOLES (Microtus pennsylvanicus) ESTABLISHED ON REVEGETATED COPPER AND NICKEL TAILINGS IN COPPER CLIFF AND URANIUM TAILINGS IN ELLIOT LAKE

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ELLIOT LAKE LABORATORY

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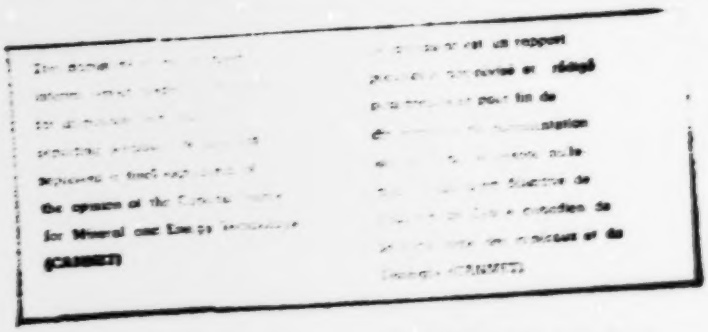

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METALS (Cu, Ni, Fe, Co, Zn, Pb) AND RADIONUCLIDE (Ra-226) LEVELS IN MEADOW VOLES (Microtus pennysylvanicus)ESTABLISHED ON REVEGETATED COPPER AND NICKEL TAILINGS IN COPPER CLIFF AND URANIUM TAILINGS IN ELLIOT LAKE

by

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ABSTRACT

Higher levels of Cu, Ni and Fe were measured in Copper Cliff tailings when compared to Elliot Lake tailings and control substrate. Elliot Lake tailings had higher levels of Pb and Ra-226 than substrate of the other two locations. Total substrate Co and Zn levels were within agricultural soil range at all three locations. Elevated levels of Ni and Fe were detected in vegetation growing on Copper Cliff tailings. Higher levels of Ra-226 were measured in vegetation growing on Elliot Lake tailings. Vegetation levels of Cu, Co and Zn did not differ between sites.

No accumulation of Cu or Co was found in meadow voles established on tailings. Ni appeared to have accumulated in livers of voles collected on Copper Cliff tailings. Elevated Fe and Zn levels were found in kidneys of Copper Cliff voles. Accumulations of Pb and Ra-226 were detected in skeletal tissues of voles established on Elliot Lake tailings.

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LES TAUX DE MÉTAUX (Cu, Ni, Fe, Co, Zn, Pb) ET DE RADIONUCLÉIDES RETROUVÉS DANS LES CAMPAGNOLS DES PRÉS (Microtus pennsylvanicus) QUI SE SONT ÉTABLIS SUR DES STÉRILES DE CUIVRE ET DE NICKEL SOUMIS AU REPEUPLEMENT VÉGÉTAL, À COPPER CLIFF ET SUR DES STÉRILES D'URANIUM À ELLIOT LAKE

par

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SOMMAIRE

De plus hauts niveaux de Cu, Ni et Fe ont été mesurés dans les stériles de Copper Cliff que dans ceux d'Elliot Lake et le sol témoin. Les stériles d'Elliot Lake avaient un niveau supérieur de Pb et Ra-226 aux sols des deux autres locations. Les niveaux de Co et Zn dans les sols des trois locations étaient semblables au niveau des sols agricoles. Des niveaux élevés de Ni et Fe ont été détectés dans la végétation croissant sur les stériles de Copper Cliff. De plus hauts niveaux de Ra-226 ont été mesurés dans le végétation croissant sur les stériles d'Elliot Lake. Les niveaux de Cu, Co. et Zn dans la végétation ne différaient pas de location en location.

Aucune accumulation de Cu et Co n'a été trouvée dans les campagnols des champs établis sur les stériles. Le Ni semble s'être accumulé dans le foie des campagnols attrapés sur les stériles de Copper Cliff. Des niveaux élevés de Fe et Zn ont été trouvés dans les reins des campagnols de Copper Cliff. Des accumulations de Pb et Ra-226 ont également été décelées dan les tissus osseux des campagnols établis sur les stériles d'Elliot Lake.

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INTRODUCTION

The purpose of the study was to compare the concentrations of metals and radionuclides in the tissues of small mammals living on three types of substrates: revegetated waste from a nickel and copper mine, revegetated waste from a uranium mine and a control area.

Little information is available concerning the relationship between metal contaminated environments and their resident fauna (Roberts et al., 1979). Revegetated tailings are, in fact, waste management area habitats that can be considered as special communities. Studies of the above nature would be valuable, as a better understanding of the contaminants uptake and their potential bioaccumulation, mobility within the ecosystem, response relationships and relative food chain transport would be gained (Johnson et al., 1978; Roberts et al., 1978).

A special situation relates to the waste from uranium mines where migration of chemical and radioactive constituents to various ecosystems is unknown. It is well known that some fission products can easily enter the food chain and disturb the ecosystem irreversibly, however, very little information exists on the release and subsequent fate of uranium-series radionuclides (Klechkovskii et al., 1971; Swanson et al., 1981). Revegetated uranium tailings offer an excellent opportunity to study accumulation of these radionuclides in the food chain.

This study was designed primarily to investigate potential accumulations of different metals and radionuclides in different tissues of small mammals that have established on revegetated tailings. Secondly, the levels of the same elements were to be investigated in the substrate and vegetation growing on tailings.

The meadow vole (Microtus pennsylvanicus) was considered to be the

most suitable small herbivorous mammalian species for this research as it was known to be present on the revegetated tailings (Wilson, 1976; Cloutier, 1980). Also, prior to the present study, not much information was available as to the levels of metals and radionuclides in individual tissues of the meadow vole established in environments having potentially elevated levels of those elements.

METHODS

STUDY SITES

Three study sites were selected: the Inco C-D tailings area (produced by copper and nickel mining operations) adjacent to the west side of Copper Cliff which is located seven km west of Sudbury, the Nordic main tailings (produced by uranium mining operations) located four km east of the town of Elliot Lake, and a control site (abandoned agricultural field) approximately seven km north-east of Massey (Fig. 1).

SAMPLING

Substrate and vegetation (composite samples including several species) samples were collected during spring and summer 1982 at all three sites. Trapping (using Victor snap traps) was conducted during all four seasons of 1982. Only meadow voles (Microtus pennsylvanicus) were retained as they were the most abundant species captured at all three locations.

Animals were sexed and aged according to the weight classes of Krebs et al. (1969): juvenile (<22 g), subadult (22-33 g) and adult (>33 g). Only subadults and adults were retained as they were most numerous.

SAMPLE PREPARATION FOR DIGESTIONS

Substrate samples were oven dried (100°C for 24 hr) and then passed through a combination of screens of different mesh sizes to remove plant debris.

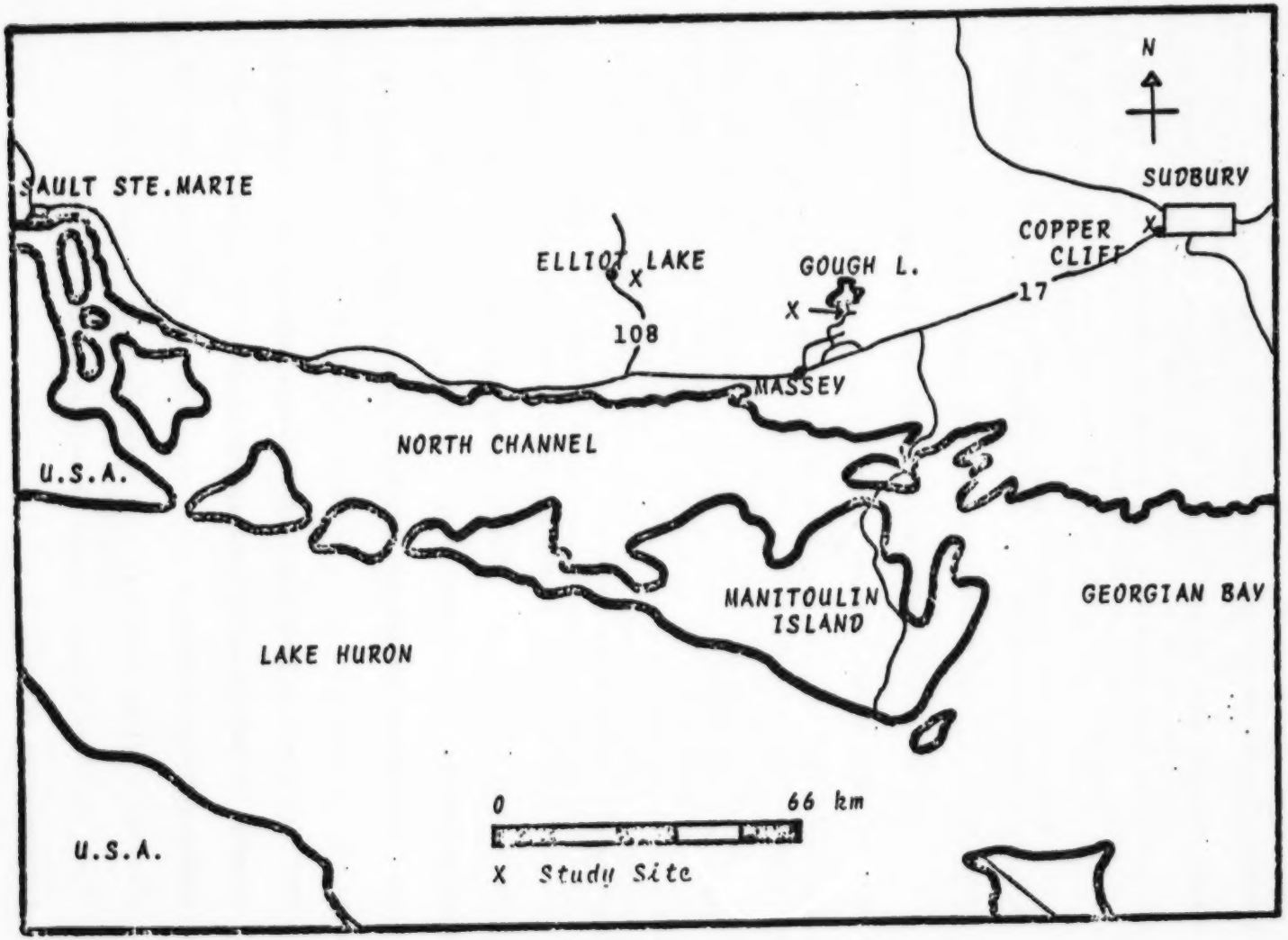

Fig. 1 - Map showing the location of the study sites.

Vegetation samples were given two baths of distilled water, oven dried (100°C for 24 hr) and then cut into lengths of 2 to 3 cm with scissors. Livers and kidneys of voles were removed and oven dried (100°C for 12 hr). Other organs and skin were stored frozen. The remaining carcasses were put in thick plastic bags which were then boiled in distilled water for two hours allowing thereafter the bones to be picked out one by one from the flesh (SRC, 1981). Bones and muscle samples were then oven dried (100°C for 12 hr).

DIGESTIONS

All glassware, teflon beakers and platinum crucibles used during digestions were washed in soapy water, rinsed with distilled water, acid washed using 50% HCl, rerinsed with distilled water and oven dried.

Dried substrate samples were weighed, placed into clean teflon beakers and then submitted to digestion (described below). Dried vegetation and vole tissue samples were weighed, placed into clean platinum crucibles, ashed slowly (temperature increased from 100°C to 450°C by 50°C every half hour) in a muffle furnace (Lindberg, Model 51894) and then submitted to digestion (described below). Temperatures were kept below 500°C to minimize volatile element losses (HASL, 1972; Koirtyohann et al., 1976).

The general procedure used for digestion was as follows. Each sample was:

1. thoroughly wetted with distilled water followed by the addition of HF (Canlab reagent grade) to dissolve silica;
2. evaporated to dryness;
3. thoroughly wetted with distilled water followed by the addition of $HClO_4$ (Baker analyzed reagent grade) to oxidize organic matter;
4. evaporated to dryness;
5. steps 3 and 4 were repeated if digestion was not complete, i.e., if black

residue was left;

6. 10 to 15 ml of distilled water was added followed by the addition of HCl (Baker analyzed reagent grade);
7. heated for five minutes to maximize homogenizing of the solution;
8. transferred to graduated cylinders and brought to a specific volume by addition of distilled water.

Three empty crucibles (blanks) were carried through each digestion run. These were used to determine the extent of metal and radionuclide contamination occurring during digestion and/or analytical work.

ANALYTICAL PROCEDURE

Metal analyses were carried out by a Rio Algom Ltd. technician using a Varian AA-475 spectrophotometer following standard procedures (Varian, 1978). Iron analyses of substrate samples were carried out by a Rio Algom Ltd. technician using a dichromate titration technique (Mertimer, 1958). Radium-226 analyses were performed by a CANMET technician using an alpha spectroscopic technique (Lim and Davé, 1981).

ANALYSIS OF DATA

Data analyses were carried out using the TOPS-20 computer and employing the ANOVA, Duncan and Kruskall Wallis programs of the SPSS package (Nie et al. 1980). Differences were deemed significant at $P < 0.05$.

The non-parametric Kruskall Wallis test was used when at least one sample, but less than half, of the sample group were below detection limits.

RESULTS AND DISCUSSION

SUBSTRATES

Copper Cliff tailings had considerably higher levels ($P < 0.05$) of

copper, nickel, and iron than Elliot Lake tailings and control substrate reflecting the high levels of those metals in the Sudburian ore (Table 1). These results were consistent with those of Crowder et al. (1982).

Elliot Lake tailings had elevated levels of lead and radium-226 ($P < 0.05$) when compared to Copper Cliff tailings and control substrate (Table 1). These observations can be explained by the fact that both of these elements are decay products of uranium-238 which is abundant in the original ore (^{238}U has a natural abundance of 99.2830%). The levels of radium-226 found in Elliot Lake tailings were consistent with those reported by Moffett and Tellier (1977).

Although cobalt and zinc levels in substrates of the three study locations did differ between sites (Table 1), all levels were within the range reported for agricultural soils of Ontario (Frank et al., 1976; Whitby et al., 1978).

VEGETATION

On several occasions, the metal concentrations in the soil can be correlated with its concentration in the vegetation growing on that substrate (Duvigneaud et al., 1963; Antonovics et al., 1971; Nicolls et al., 1965). Therefore, it was believed that potential higher concentrations of metals and radionuclides in the vegetation growing on tailings, when compared to control levels, could be reflecting the higher total substrate levels of those elements in the tailings.

Higher levels of nickel and iron ($P < 0.05$) were detected in Copper Cliff vegetation when compared to Elliot Lake and control levels (Table 2) thus reflecting the high levels of these two metals in the substrate of Copper Cliff tailings. Crowder et al., (1982) and Wilson (1976) reported similar observations. On the other hand, copper levels in vegetation of Copper Cliff

Table 1 - Total metal and radionuclide concentrations* in substrates of tailings and control sites

	COPPER CLIFF Copper and Nickel Tailings	ELLIOT LAKE Uranium Tailings	CONTROL Abandoned Agricultural Field
Copper	405.7±29.4 (5)a**	37.6±4.4 (3)b	26.6±4.5 (3)b
Nickel	368.4±26.2 (5)c	7.2±0.3 (3)d	38.4±2.7 (3)d
Iron	107,600±2,135 (5)e	8,133±1,822 (3)f	25,757±362 (3)g
Cobalt	47.4±1.8 (5)h	10.1±1.1 (3)i	26.0±0.4 (3)j
Zinc	90.3±11.9 (5)k	5.6±0.5 (3)l	78.5±12.4 (3)k
Lead	64.5±3.9 (5)m	212.8±13.8 (3)n	28.9±3.7 (3)o
Radium-226	0±0 (4)p	177±30 (3)q	0±0 (3)p

* Mean ±1 standard error in $\mu g.g^{-1}$ dry weight for all metals, and in $pCi.g^{-1}$ dry weight for Ra-226; number of samples in parentheses.

** Values with same subscripts are not significantly different ($P > 0.05$), as indicated by Duncan range test.

Table 2 - Total metal and radionuclide concentrations* in vegetation (mixed spp.) of tailings and control sites.

	COPPER CLIFF Copper and Nickel Tailings	ELLIOT LAKE Uranium Tailings	CONTROL Abandoned Agricultural Field
Copper	16.5±2.3 (5)a**	18.1±7.7 (3)a	6.4±1.2 (3)a
Nickel	17.9±4.5 (4)b	2.4±0.6 (3)c	1.2±0.1 (3)c
Iron	186.0±36.3 (5)d	65.9±9.4 (3)e	59.0±4.4 (3)e
Cobalt	0.8±0.2 (5)f	0.7±0.2 (3)f	0.6±0.1 (3)f
Zinc	13.0±1.8 (5)g	11.2±0.8 (3)g	18.6±3.2 (3)g
Lead	undetect-1.1 (5)	undetect-2.0 (3)	undetect (3)
Radium-226	0±0 (4)h	9±3 (3)i	0±0 (3)h

* Mean ±1 standard error in $\mu g.g^{-1}$ dry weight for all metals, and in $pCi.g^{-1}$ dry weight for Ra-226; number of samples in parentheses. Range is shown where some samples were below direction limits.

** Values with same subscripts are not significantly different ($P > 0.05$), as indicated by Duncan range test.

Values marked "undetect" were below detection limits.

tailings did not differ ($P > 0.05$) from control levels (Table 2) contrary to the observations of Crowder et al. (1982). This latter discrepancy is believed to have been caused by sampling technique differences (difference in sampling schedule, difference in species collected).

Higher levels of radium-226 ($P < 0.05$) were found in Elliot Lake vegetation (Table 2) reflecting the elevated levels of that radionuclide in the substrate of that site. Similar results were reported by Moffett and Tellier (1977). Lead levels were below detection limits in vegetation of all three sites (Table 2) which led us to believe that potential lead accumulation in vegetation growing on tailings was minimal.

Cobalt and zinc levels in the vegetation growing on tailings were similar ($P > 0.05$) to control levels (Table 2). These observations did reflect the total substrate levels of those two metals which were within agricultural soil ranges as mentioned previously.

MEADOW VOLES (M. Pennsylvanicus)

Smith and Rongstad (1982) have reported high zinc and copper levels in total body of M. pennsylvanicus established at an active zinc-copper mine near Timmins. Schlesinger and Potter (1974) found a higher total body lead in roadside M. pennsylvanicus when compared to control samples. Zoheir et al. (1979) reported a higher total body radium-226 in M. pennsylvanicus established near a rich uranium ore body. Therefore, it was hypothesized that meadow voles established on tailings might accumulate those elements which were found to be elevated in substrates and vegetation of tailings sites.

The liver and kidneys are considered to have a high capacity to bind chemicals, and therefore probably concentrate more toxicants than any other organ (Klaassen, 1980). Therefore, if toxicants are present in

high levels in the diet of voles, it could be assumed that the livers and kidneys of those animals might accumulate them.

According to Table 3, copper, iron, zinc and cobalt levels of the liver were similar ($P > 0.05$) between sites indicating that dietary levels of those metals for voles established on tailings were not sufficiently elevated to cause their accumulation or that liver of M. pennsylvanicus does not accumulate metals. Liver lead levels (Table 3) were below detection limits in most samples of all three sites which led us to believe that potential accumulation of this metal in voles on tailings was minimal. Nickel, on the other hand, appeared to accumulate in livers of Copper Cliff voles (Table 3) thus reflecting the elevated levels of this metal found in the substrate and vegetation of Copper Cliff tailings. Further analysis with a more sensitive technique would be required to confirm this.

Kidney copper concentrations (Table 4) did not differ between sites ($P > 0.05$) indicating that dietary copper levels of voles collected on tailings did not differ sufficiently from control levels to cause accumulation of this metal in kidneys, or that this latter tissue in M. pennsylvanicus does not accumulate copper. Kidney iron and zinc levels of Copper Cliff voles were found to be higher ($P < 0.05$) than in control and Elliot Lake samples respectively (Table 4). These observations appear to reflect the higher levels of iron and zinc found in the Copper Cliff substrate when compared to the control and Elliot Lake levels respectively.

Kidney nickel, cobalt and lead levels were below detection limits (Table 4) for most samples and therefore prevented us from drawing firm conclusions concerning their accumulations in kidneys of voles established on tailings.

Muscles were not considered as a major storage site of toxicants by

Table 3 - Metal concentration* ($\mu g.g^{-1}$ dry weight) in livers of *Microtus pennsylvanicus* collected at tailings and control sites, based on results pooled for sex, age cohort (weight class) and seasons.

METALS	COPPER CLIFF Copper and Nickel Tailings (N=24)	ELLIOT LAKE Uranium Tailings (N=26)	CONTROL Abandoned Agricultural Field (N=21)
Copper	54.7±18.4a**	37.3±7.7a	33.8±9.3a
Nickel***	undetect - 9.9	undetect - 6.8	undetect - 8.7
Iron	692.4±118.9b	483.6±44.0b	480.8±33.4b
Cobalt†	undetect - 6.0	undetect - 7.9	undetect - 5.0
Zinc	69.8±4.0c	65.4±3.8c	73.2±2.3c
Lead††	undetect - 3.8	undetect -5.1	undetect - 4.4

* Mean ±1 standard error; number of samples in parentheses. Range is shown where some concentrations were below detection limits.

** Values with same subscripts are not significantly different ($P > 0.05$), as indicated by Duncan range test.

*** Metal concentrations are significantly different ($P < 0.05$) between sites, as indicated by Kruskall-Wallis test.

† Metal concentrations are not significantly different ($P > 0.05$) between sites, as indicated by Kruskall-Wallis test.

†† Too many values were below detection limits to permit statistical analysis.

Values marked "undetect" were below detection limits.

Table 4 - Metal concentration* ($\mu g.g^{-1}$ dry weight) in kidneys of Microtus pennsylvanicus collected at tailings and control sites. Concentration values are based on results pooled for sex, age cohort (weight class) and seasons.

Metals	COPPER CLIFF Copper and Nickel Tailings (N=24)	ELLIOT LAKE Uranium Tailings (N=24)	CONTROL Abandoned Agricultural Field (N=21)
Copper	76.4±19.2a**	102.4±50.5a	71.3±30.4a
Nickel†	undetect - 18.4	undetect - 24.0	undetect - 25.3
Iron	461.1±33.2b	384.1±39.3bc	321.8±31.3c
Cobalt†	undetect - 26.4	undetect - 29.5	undetect - 35.5
Zinc	80.8±3.0d	68.3±2.5e	71.9±4.3de
Lead†	undetect - 38.8	undetect - 37.3	undetect - 20.0

* Mean ±1 standard error; number of samples in parentheses. Range is shown where some concentrations were below detection limits.

** Values with same subscripts are not significantly different ($P > 0.05$), as indicated by Duncan range test.

† Too many values were below detection limits to permit statistical analysis.

Values marked "undetect" were below detection limits.

Klaassen (1980). No accumulations of elements were therefore expected in muscles of voles established on tailings. The results of Table 5 did agree with the latter expectation. These observations reflect the poor ability of muscular tissue to accumulate contaminants and/or the similarity of dietary contaminant levels at each of the three locations.

Bones were reported as a major storage site for toxicants (Klaassen, 1980). Skeletal cobalt levels (Table 6) were not found to differ between sites as was the case for vegetation discussed previously. Similarly, total substrate cobalt levels of tailings were not found to differ drastically from agricultural soil levels. Therefore, skeletal cobalt levels of meadow voles are consistant with environmental cobalt levels. On the other hand, total substrate lead and radium-226 levels were found to be higher in Elliot Lake tailings as was the case for total vegetation radium-226 levels. Similarly, skeletal lead and radium-226 (Table 6) levels were found to be higher ($P < 0.05$) in Elliot Lake samples thus indicating an accumulation of both elements.

CONCLUSIONS

Elevated copper levels present in Copper Cliff tailings did not cause accumulation of this metal in meadow voles established at that site. On the other hand, the high levels of nickel and iron detected in the substrate and vegetation of Copper Cliff tailings appeared to have caused accumulation of nickel and iron in liver and kidneys of meadow voles respectively.

The higher levels of zinc found in Copper Cliff tailings when compared to Elliot Lake tailings did correlate with a higher kidney zinc level measured in Copper Cliff voles when compared to Elliot Lake voles.

Cobalt levels in substrate and vegetation of tailings did not differ markedly from control levels which was reflected in the cobalt concentrations

Table 5 - Metal concentration* ($\mu g.g^{-1}$ dry weight) in muscles of Microtus pennsylvanicus collected at tailings and control sites. Concentration values are based on results pooled for sex, age cohort (weight class) and seasons.

Metals	COPPER CLIFF Copper and Nickel Tailings	ELLIOT LAKE Uranium Tailings	CONTROL Abandoned Agricultural Field
Copper	11.6±1.1 (24)a†	13.5±1.9 (27)a	10.6±0.8 (21)a
Nickel	5.9±0.7 (24)b	6.7±1.3 (27)b	5.5±0.8 (21)b
Iron	181.6±9.5 (18)c	169.4±9.7 (21)c	171.0±8.6 (18)c
Cobalt**	undetect - 1.7	undetect - 2.3	undetect - 1.9
Zinc	37.3±2.3 (24)d	41.3±2.5 (27)d	37.6±2.4 (21)d
Lead**	undetect - 2.9	undetect - 4.7	undetect - 3.8

* Mean ±1 standard error; number of samples in parentheses. Range is shown where some concentrations were below detection limits.

† Values with same subscripts are not significantly different ($P > 0.05$), as indicated by Duncan range test.

** Metal concentrations are not significantly different ($P > 0.05$) between sites, as indicated by Kruskall-Wallis test.

Values marked "undetect" were below detection limits.

Table 6 - Metal and radionuclide concentrations* in bones of Microtus pennsylvanicus collected at tailings and control sites. Concentration values are based on results pooled for sex, age cohort (weight class) and seasons.

Contaminants	COPPER CLIFF Copper and Nickel Tailings (N=24)	ELLIOT LAKE Uranium Tailings (N=38)	CONTROL Abandoned Agricultural Field (N=30)
Cobalt	7.3±0.2a**	7.1±0.1a	7.1±0.2a
Lead	14.7±1.0b	18.4±0.7c	15.1±0.5b
Radium-226	0±0d	64±8e	0±0d

* Mean ±1 standard error in $\mu g.g^{-1}$ dry weight for cobalt and lead, and in $pCi.g^{-1}$ dry weight for radium-226; number of samples in parentheses.

** Values with same subscripts are not significantly different ($P > 0.05$), as indicated by Duncan range test.

of various tissues of meadow voles collected at those sites.

Elevated lead and radium-226 levels were found in Elliot Lake tailings. Elevated radium-226 levels were also found in vegetation growing on Elliot Lake tailings. These higher environmental levels of these two elements caused their accumulation in skeletal tissues of meadow voles established at that site.

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